The A-Star Puzzle
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The dependence of the energy distribution on the abundances of A-star atmosphere models

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Abstract. We calculated the energy distributions of A-star atmospheres ($T_{\rm eff} = 10\,000\,{\rm K}, \log g = 4.0$) for ranges of the abundances of silicon and other light chemical elements using adequate model atmospheres. We discuss the reasons for and the magnitudes of the calculated departures of the stellar energy distribution and *uvby* magnitudes from those of normal stars.

Keywords. Radiative transfer, stars: atmospheres, stars: chemically peculiar, stars: early-type

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1. Introduction

Magnetic chemically peculiar (mCP) stars exhibit periodic variations of their light and energy distributions which more or less differ from those of normal stars with the same effective temperature $T_{\rm eff}$ and surface gravity g. Observed light variations (the amplitude of which reaches typically several hundredths of magnitude) used to be explained by the presence of specific "photometric" spots with different energy distributions on the surfaces of rotating stars. It is believed that these hypothetical photometric spots are somehow connected with the "spectroscopic" spots with enhanced abundance of various chemical elements such as the iron group, silicon, strontium, and the Rare Earths. While the location and detailed properties of these spots can be determined and mapped from a Doppler imaging profile analysis (e.g., Khokhlova *et al.* 1997), in the case of photometric spots such a tool is not in our disposal. The departures of the energy distribution in the spectra of CP stars are as a rule explained as the consequence of line blanketing caused by plenty of lines of overabundant elements namely in the UV region of stellar spectra (Peterson 1970, Molnar 1973). This general concept deserves a thorough quantitative verification by the new tools of precise multicolor photometry and spectrophotometry and advanced stellar atmosphere modelling.

This paper presents first answers to question whether the above mentioned paradigm may be valid or it belongs only among astrophysical myths.

2. Models

For the modelling of A star atmospheres we selected the TLUSTY code (Hubeny & Lanz 1992, 1995, Lanz & Hubeny 2003). Using this code we calculated LTE plane-parallel model atmospheres for various abundances which are typical for chemically peculiar A stars. For our study we used the model of a Main Sequence A star with the parameters $T_{\text{eff}} = 10\,000\,\text{K}$, $\log g = 4.0$, $\zeta_{\text{turb}} = 2\,\text{km}\,\text{s}^{-1}$. Elements and their ionization stages accounted for in the model atmosphere calculation are given in Table 1.

Table 1. Elements and their ionization stages in the model atmosphere calculation.

Ion	Levels	Ion	Levels	Ion	Levels	Ion	Levels
H I	9	N I	21	Ne I	15	Si I	16
H II	1	N II	26	Ne II	15	Si II	16
He I	14	N III	1	Ne III	1	Si III	12
He II	14	O I	12	Mg I	13	Si IV	1
He III	1	O II	13	Mg II	14		
C I	26	O III	1	Mg III	14		
C II	14			Mg IV	1		
C III	1						

The emergent radiative flux is afterwards found with the spectrum synthesis program SYNSPEC. For the calculation of the emergent spectrum we include the line transitions of all atoms with atomic number $Z \leqslant 30$. Finally, with the calculated spectral energy distribution it is possible to define departures of *uvby* magnitudes for a particular abundance A of a selected element from the situation when its abundance was equal to the solar

$$\Delta m_c(A) = -2.5 \log \left(\frac{H_c(A)}{H_c(A_\odot)} \right).$$

The fluxes $H_c(A)$, $H_c(A_\odot)$ in individual colors c for model are given by the convolution of radiative flux H_λ with a Gauss function with peak at the central wavelengths of given colors and halfwidths taken from Cox (2000).

3. Dependence of the calculated fluxes on the silicon abundance.

To better understand the dependence of the calculated magnitudes on elemental abundance we discuss the impact of a variable silicon abundance on the radiative flux in the optical spectrum. In Figure 1 we plot calculated continuum radiative fluxes in the wavelength range studied for different abundances of silicon.

For the solar silicon abundance $(A/A_\odot)_{\text{Si}} = 1$ model atmosphere the optical radiative flux is dominated by the Balmer jump and Paschen continuum. With an increasing abundance of silicon the radiative flux in the wavelength domain studied increases. This is caused mainly by the photoionization of Si I from the ground and first excited levels which increases opacity in the UV region. The absorbed UV energy is then redistributed into the near UV and the optical. However, with increasing silicon overabundances the situation changes. The atmosphere becomes silicon dominated and the importance of the hydrogen Balmer jump diminishes. Consequently, for the highest silicon abundances the emergent spectrum is given also by silicon bound-free transitions and jumps due to the photoionization of different Si levels occur.

The nature of the influence of the variation of the silicon abundance on the photometric variability can be well demonstrated by the ratio of radiative fluxes of the model with the silicon abundance A versus the fluxes of the model with solar abundance expressed in magnitudes (see Figure 2). We compared the model fluxes smoothed by the Gaussian filter with $\sigma = 85\,\text{Å}$.

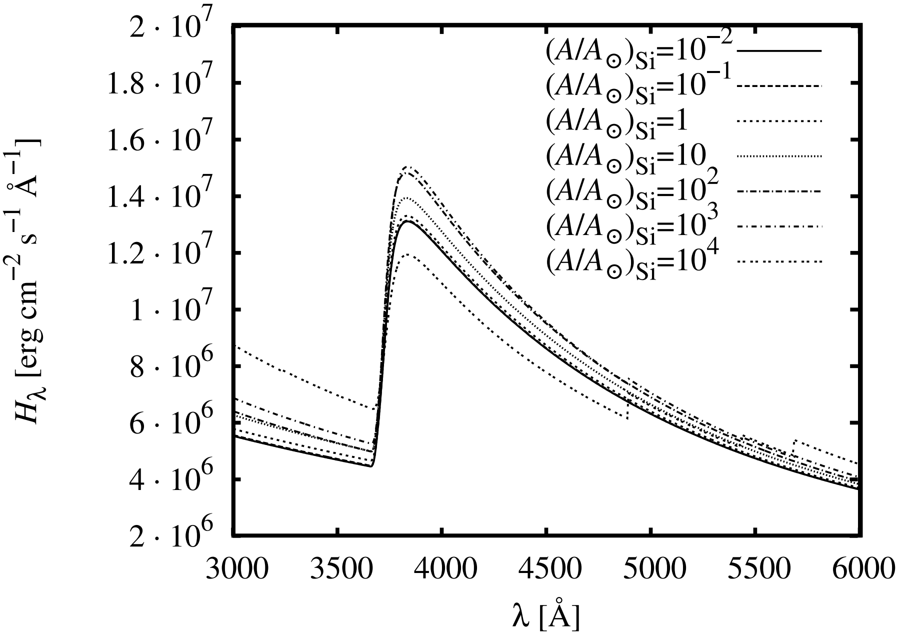

Figure 1. Continuum radiative flux for different abundances of silicon.

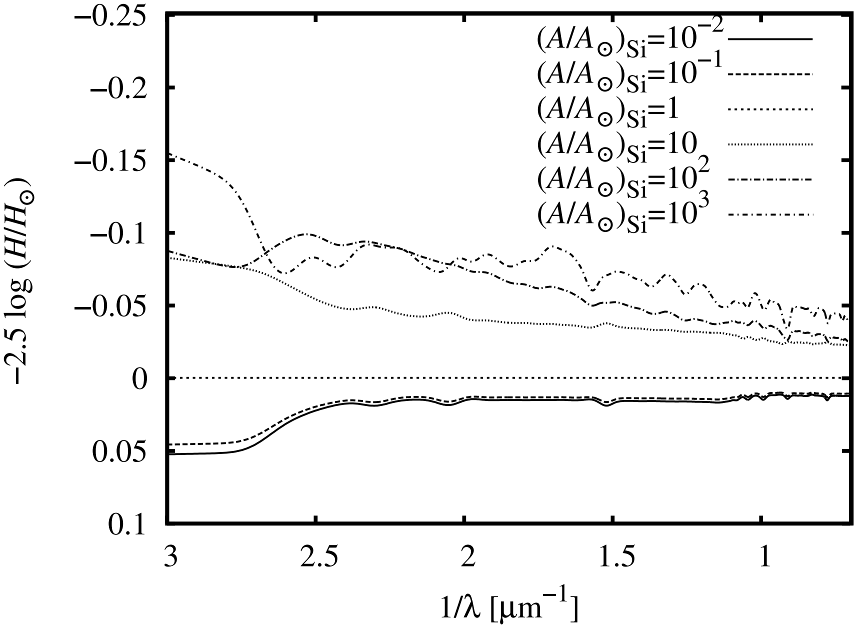

Figure 2. Smoothed ratio of radiative fluxes of the models with selected abundance relatively to the flux of the model with solar composition expressed in magnitudes.

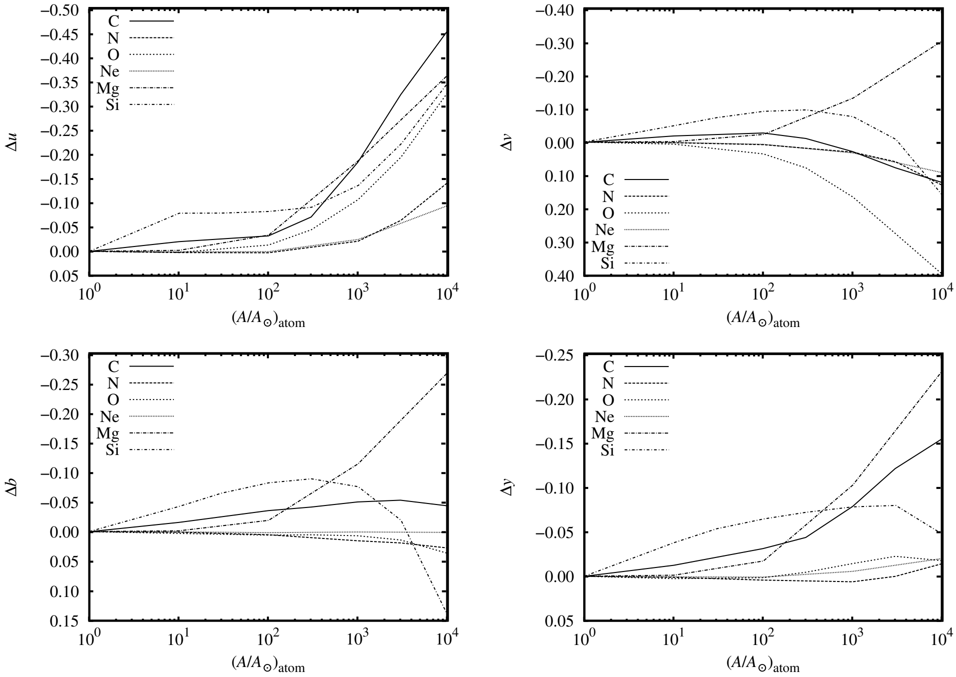

Figure 3. Photometric variations due to the different abundances.

The advantage of this diagram is that the photometric variations can be easily deduced from it. As has been discussed in the previous paragraphs, the flux variations are dominated by the redistribution of the flux from the short-wavelength part of the spectrum to longer wavelengths due to the bound-free transitions. Hence, for lower overabundances the radiative flux increases in the displayed region and consequently the star is brighter in photometric colors. Apparently, the relative brightness increase is greater for shorter wavelengths, what is in accordance with reality. However, for higher overabundances the star becomes silicon dominated and the photometric variations are more complicated. Anyway, it is remarkable that significant variations of the observed magnitudes occur already for a relatively small departures from the solar composition.

For other elements the situation is similar. Detailed photometric variations are given mainly by the magnitude of bound-free cross-section of individual levels of ions and by the location of level ionization thresholds which are manifested in the occurrence of jumps.

4. *uvby* variations

Abundance variations discussed in the previous section may cause photometric variations. Again, because the spectroscopic variations due to the elements studied are given mainly by the variations of bound-free absorption, the photometric variations can be also explained by the variations of bound-free absorption coefficient.

The photometric variations (Figure 3) are dominated mainly by the discussed redistribution of radiative flux from the short-wavelength side of UV domain to near UV and optical domains and by the occurrence of jumps due to the different bound-free transitions of elements studied.

5. Conclusions

We have shown that the theoretical spectral energy distribution really significantly depends on the elemental abundances. Contrary to the common belief that flux and photometric variations are caused mainly by the line transitions we have shown that these variations are given mainly by *bound-free transitions* (at least for elements studied). For slightly increased elemental abundances the variations are dominated by the redistribution of flux from the short-wavelength part of the UV domain to the near UV and optical. For very high overabundances the spectral energy distribution becomes dominated by the overabundant element and changes even more significantly.

Although our models are very simple, since the inclusion of further elements is necessary, it seems to be plausible that the photometric variability of some chemically peculiar stars (at least those with silicon overabundances) might be explained by the deviations from the solar composition. The typical amplitude of photometric variability is of order several hundredths of magnitude. Taking into account that the spectroscopic spots occupy only a part of the stellar surface, already reasonable overabundances of the individual elements (of order 10–100, especially that of silicon) may cause observed light variability.

A more detailed study of the problem will be published elsewhere.

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